

# APPARATUS AND METHOD FOR ROTATING THE DISPLAY ORIENTATION OF A CAPTURED IMAGE

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This application relates to co-pending U.S. patent application Ser. No. 08/355,031, entitled A System and Method For Generating a Contrast Overlay as a Focus Assist for An Imaging Device, filed on Dec. 13, 1994, by inventor Eric C. Anderson; and U.S. patent application Ser. No. 08/384,012, entitled Apparatus and Method for Camera Image and Orientation Capture, filed on Feb. 6, 1995, by inventor Scott Fullam. The subject matter of the two applications described above is hereby incorporated by reference. These related applications are commonly assigned to Apple Computer, Inc.

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates generally to an apparatus and method for orienting an image. More particularly, the present invention is an apparatus and method for rotating a captured image to an orientation corresponding to an imaging subsystem's orientation at the time in which the image was captured.

### 2. Description of the Background Art

When a digital camera captures an image of an object, the camera's frame of reference with respect to the object produces a desired image orientation. Two conventional image orientations exist, namely, a landscape orientation and a portrait orientation. Referring now to FIG. 1A, a prior art graphical representation of an object in a landscape orientation is shown, in which the image's width is greater than its height. Referring also now to FIG. 1B, a prior art graphical representation of the object in a portrait orientation is shown, in which the image's height is greater than its width.

In a digital camera, an image sensor is comprised of light-sensitive devices, such as charge-coupled devices (CCD), that convert an optical image into a set of electrical signals. Referring now to FIG. 1C, a prior art image sensor is shown having a 480 row by 640 column matrix of light collecting pixels. The image sensor is orientated within a body of the digital camera so that a first row of pixels (i.e. row  $r_1$ ) corresponds to the bottom of an upright and level digital camera. This image sensor orientation is required since as an optical image passes through a conventional camera lens it is inverted. The image sensor in a color digital camera typically consists of an array of green (G), red (R) and blue (B) pixels. Alternative embodiments include sensors detecting cyan, magenta, yellow and green as is typically used in video cameras. Other image sensor configurations are also used. The pixels that comprise the image sensor are arranged into various patterns or formats. A common image sensor format is called a Bayer pattern. The Bayer pattern format is defined as a pixel pattern comprised of 50% green-light responsive pixels, 25% red-light responsive pixels and 25% blue-light responsive pixels arranged in alternating rows of "GRGRGR" and "BGBGBG," as shown in FIG. 1C. Throughout this specification, "G" means "green," "R" means "red," and "B" means "blue."

Once an image is captured by the digital camera, a set of pixel signals corresponding to the image received by the pixels is processed by an image processing algorithm. Image processing routines are conventionally designed to process pixel signals line-by-line, conforming to a specific and unchanging pixel pattern format. Thus, image sensors manu-

factured with the Bayer pixel pattern format will be coupled to image processing routines specifically designed to accept pixel signals in alternating sequences of "GRGRGR" and "BGBGBG." Due to possible imperfections in the outer rows and columns of pixels that make up the image sensor, conventional digital cameras sometimes have image sensors large enough so that one or more lines of pixels at the sides of the image sensor can be ignored.

Referring now to FIG. 1D, a prior art graphical representation is shown of the object as captured in the portrait orientation and output upon an image display 100. The image display 100 is typically a conventional stand-alone, personal computer CRT having a top 102, a right side 104, a left side 106 and a bottom 108.

As previously described, the image processing routines within digital cameras are conventionally designed to process pixel signals on a line-by-line basis according to only one pixel pattern format. Thus, conventional digital cameras process images as if they were always in a landscape format. In the presentation of the landscape image of FIG. 1A upon the image display, the "TOP" (i.e. "top portion") of the landscape image would correspond to the top 102 of the FIG. 1D image display 100. Such an orientation for landscape images on the image display 100 is quite natural and is acceptable for ease of viewing the image. However, the presentation of the portrait image of FIG. 1B upon the image display results in the "TOP" of the portrait image corresponding to either the right side 104 or the left side 106 of the image display 100, depending on how the user had rotated the digital camera. FIG. 1D explicitly shows the case where the "TOP" of the portrait image corresponds to the right side 104 of the image display 100. This "sideways" orientation for portrait images on the image display 100 is unacceptable and unnatural. This undesirable by-product of conventional digital cameras requires that the user rotate portrait images so that they are presented in a more natural and upright viewing angle on the image display 100. It should be noted that this problem also exists for digitized images from conventional film cameras. Traditional rotation methods also have the disadvantage of requiring two blocks of memory to rotate a stored image.

What is needed is an apparatus and method that efficiently and automatically rotates a stored photographic image to correspond to the orientation in which the photographic image was captured.

## SUMMARY OF THE INVENTION

The present invention is an apparatus and method for rotating the display orientation of a captured image. The apparatus of the present invention preferably comprises an image sensor, an orientation sensor, a memory and a processing unit. The image sensor is used for capturing image data. The orientation sensor is coupled to the image sensor, and is used for generating a portrait signal if the image sensor is positioned in a portrait orientation relative to the object. The memory, has an auto-rotate unit comprising program instructions for transforming the captured image data into rotated image data in response to the portrait signal. The processing unit, is used for executing program instructions stored in the memory, and is coupled to the image sensor, the orientation sensor and the memory.

The method of the present invention preferably comprises the steps of: generating image data representative of an object with an image sensor; identifying an orientation of the image sensor relative to the object during the generating step; and selectively transferring the image data to an image processing unit in response to the identifying step.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A, is a prior art graphical representation of an object in a landscape orientation;

FIG. 1B, is a prior art graphical representation of the object in a portrait orientation;

FIG. 1C, is a prior art 480 row by 640 column image sensor;

FIG. 1D, is a prior art graphical representation of the object as captured in the portrait orientation and output upon an image display;

FIG. 2, is a block diagram of a preferred embodiment of an apparatus for rotating the display orientation of a captured image;

FIG. 3A, is a block diagram of a preferred embodiment of an imaging subsystem of the present invention;

FIG. 3B, is a first graphical representation of a preferred embodiment of an image sensor disposed within the present invention;

FIG. 3C, is a second graphical representation of a preferred embodiment of the image sensor within the present invention;

FIG. 4A, is a block diagram of a preferred embodiment of a processing and storage subsystem of the present invention;

FIG. 4B, is a block diagram of a preferred embodiment of a volatile memory within the processing and storage subsystem;

FIG. 4C, is a block diagram of a preferred embodiment of a frame buffer data structure within a frame buffer;

FIG. 4D, is a block diagram of the preferred embodiment of a non-volatile memory within the processing and storage subsystem;

FIG. 5A, is a graphical representation of a preferred embodiment of portrait\_left image data within the frame buffer data structure;

FIG. 5B, is a graphical representation of a preferred embodiment of portrait\_right image data within the frame buffer data structure;

FIG. 5C, is a graphical representation of a preferred embodiment of landscape image data within the frame buffer data structure; and

FIGS. 6A, 6B, 6C and 6D, are a flowchart of a preferred method for rotating the display orientation of a captured image.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is an apparatus and method for rotating the display orientation of a captured image.

Referring now to FIG. 2, a block diagram is shown illustrating a camera 200 for rotating a display orientation of a captured image. In the preferred embodiment, the camera 200 is a digital camera, such as a QuickTake 150, by Apple Computer of Cupertino, Calif. The camera 200 preferably comprises an imaging subsystem 204, a bus 206 and a processing and storage subsystem 208. Reflected light from an object 202 is conventionally captured by the imaging subsystem 204 via a button press or some other action. The captured image data is transferred over the bus 206 to the processing and storage subsystem 208, which stores the data in internal memory. The bus 206 also passes various status and control signals between the imaging subsystem 204 and the processing and storage subsystem 208, as will be further discussed below.

Referring now to FIG. 3A, a block diagram is shown illustrating the imaging subsystem 204 of the present invention. The imaging subsystem 204 preferably comprises a lens 300 having an iris, an optical filter 302, an image sensor 304, a timing generator 306, an analog signal processor (ASP) 308, an analog-to-digital (A/D) converter 310, a digital signal processor (DSP) 320, a right/left orientation sensor (RLOS) 324, an up/down orientation sensor (UDOS) 326 and one or more motors 312. U.S. patent application Ser. No. 08/355,031, entitled A System and Method For Generating a Contrast Overlay as a Focus Assist For An Imaging Device, filed on Dec. 13, 1994 is incorporated herein by reference and provides a detailed discussion of the preferred elements in the imaging subsystem 204, with the exception of the RLOS 324 and the UDOS 326. U.S. patent application Ser. No. 08/384,012, entitled Apparatus and Method for Camera image and Orientation Capture, filed on Feb. 6, 1995 is incorporated herein by reference and provides a detailed discussion of various embodiments of the RLOS 324 and the UDOS 326, which are further discussed below. Briefly, the imaging subsystem 204 captures an image of the object 202 via light impacting the image sensor 304 along an optical path 314. The image sensor 304 in turn generates a set of pixel signals representative of the captured image data. After being processed by the ASP 308, the A/D converter 310 and the DSP 320, the captured image data passes over the bus 206 to the processing and storage subsystem 208. The functions performed by the DSP 320 may alternatively be performed in the processing and storage subsystem 208.

Referring now to FIG. 3B, a graphical representation is shown illustrating the image sensor 304 disposed within the camera 200. FIG. 3B shows the camera 200 maintained in a landscape orientation while directly facing the object 202. The image sensor 304 has a front 338 and a top 336, which are juxtaposed with a front 334 and a bottom 332 of the camera 200 respectively. The front side 338 of the image sensor 304 comprises light-sensitive pixels, which capture an image received along the optical path 314 and through the lens 300 mounted upon the camera 200. It should be noted that the image recorded by the image sensor 304 is inverted relative to the object by the lens 300. The front 338 of the image sensor 304 preferably forms a planar surface as shown in perspective in FIG. 3B. When the image sensor 304 is oriented as shown in FIG. 3B, a landscape image of the object 202 is captured. When the camera 200 is rotated either 90° clockwise or 90° counterclockwise about the x-axis, a portrait image of the object 202 is captured.

Referring now to FIG. 3C, a graphical representation is shown illustrating the image sensor 304, which has the top 336, a right side 342, a left side 340 and a bottom 344. The image sensor 304 is comprised of a plurality of pixels arranged in an i-row by j-column array. In the preferred embodiment, the pixels are arranged in a Bayer pattern format. Alternatively the present invention may be applied to image sensors of various sizes and image processing routines designed to process pixel signals arranged in patterns or formats different from the Bayer pattern.

As stated above, the RLOS 324 (i.e. the right/left orientation sensor) and the UDOS 326 (i.e. the up/down orientation sensor) are disposed within the imaging subsystem 204. Both the RLOS 324 and the UDOS 326 are physically coupled to the image sensor 304 and electrically coupled to the DSP 320. The RLOS 324 monitors whether the camera 200 is in a landscape orientation or a portrait orientation. If the camera 200 is in a portrait orientation, the RLOS 324 identifies whether the camera 200 has been rotated clockwise or counterclockwise, as viewed from the rear of the

camera 200. In response to such camera 200 rotation, the RLOS 324 generates and transmits either a landscape signal, a portrait\_left signal or a portrait\_right signal to the DSP 320. More specifically, if the camera 200 is held in the landscape orientation shown in FIGS. 1A and 3B, the RLOS 324 generates the landscape signal, since the top 336 of the image sensor 304 corresponds to the "TOP" of the object 202. However, if the camera 200 is rotated 90° clockwise about the x-axis, as viewed from the rear of the camera 200 shown in FIG. 3B, the RLOS 324 generates the portrait\_right signal, since now the right side 342 of the image sensor 304 corresponds to the "TOP" of the object 202. And, if the camera 200 is rotated 90° counter-clockwise about the x-axis, as viewed from the rear of the camera 200, the RLOS 324 generates the portrait\_left signal, since now the left side 340 of the image sensor 304 corresponds to the "TOP" of the object 202.

The UDOS 326 monitors whether the camera 200 is in either a level orientation or an off-level orientation. In response to a movement of the camera 200, the UDOS 324 generates and transmits either a level signal or an off-level signal to the DSP 320. Specifically, if the camera 200 is held in the landscape orientation shown in FIG. 3B, the UDOS 324 generates the level signal, since the front 334 of the camera 200 directly faces the object 202. If the camera 200 is rotated more than 45° clockwise or counter-clockwise about the y-axis, shown in FIG. 3B, the UDOS 324 preferably generates the off-level signal, since the front 334 of the camera 200 now points either above or below the x-y plane. Alternative embodiments of the present invention can change the specific measure of rotation necessary to generate the off-level signal from 45° to any number from 0° to 180°.

Both the RLOS 324 and UDOS 326 sensors are preferably identical in their structure and function. Their placement relative to the image sensor 304 determines whether the signal generated by the orientation sensor is one of the RLOS 324 signals or the UDOS 326 signals. The DSP 320 receives both the RLOS 324 and the UDOS 326 signals and transmits them to the processing and storage subsystem 208 over the bus 206. While the preferred embodiment of the present invention incorporates the orientation sensors 324, 326, those skilled in the art will recognize that the orientation sensors 324, 326 are not required to practice the present invention, if the processing and storage subsystem 208 prompts the photographer for the camera's 200 orientation at the time an image is captured. Alternatively, an embodiment using only the RLOS 324 enables practicing of the present invention, but this alternative embodiment results in loss of the off-level signal. However, such an embodiment using only the RLOS 324 is still useful for most applications requiring only landscape and portrait orientation using an approximately level camera 200. A further alternative embodiment includes an RLOS 324 which only generates the landscape, portrait\_left, or portrait\_right signals if the camera 200 is within a predetermined level range.

Referring now to FIG. 4A, a block diagram is shown illustrating the processing and storage subsystem 208 of the present invention. The processing and storage subsystem 208 comprises a buffer 400, a processing unit 404, a non-volatile memory 406, an input device 408, a volatile memory 410 and an I/O interface 414, coupled together via an internal bus 402. In the preferred embodiment, the processing and storage subsystem 208 is conventionally embedded as part of the camera 200. Alternatively, the processing and storage subsystem 208 may be a desktop type computer.

The buffer 400 is preferably a first-in, first-out buffer for temporarily holding the captured image data and the imaging subsystem 204 control signals passed between the DSP 320 and the processing and storage subsystem 208. The buffer 400 has data lines that are coupled to both the bus 206 and the internal bus 402. The processing unit 404 executes programming instructions stored in the non-volatile memory 406 and the volatile memory 410 to perform various operations. The non-volatile memory 406 stores a set of computer readable program instructions for controlling how the processing unit 404 accesses, transforms and outputs the image data, as described in detail below with reference to FIG. 4D. While the non-volatile memory 406 is preferably a Read Only Memory (ROM), alternatively the non-volatile memory 406 could be replaced with a functionally equivalent computer useable medium such as: a compact disk and drive; a floppy disk and drive; or a memory card. Additional details on the function and operation of both the non-volatile memory 406 and the volatile memory 410 are provided below with reference to FIGS. 4B and 4D.

The input device 408 is preferably a series of control buttons, responsive to user inputs, which generates signals that are translated by the processing unit 404 into control signals to adjust the focus and other operating parameters of the imaging subsystem 204. As mentioned above, while the preferred embodiment of the camera 200 incorporates the RLOS 324 and UDOS 326, an alternative embodiment of the present invention prompts the user to manually input, via the input device 408, the imaging subsystem's 204 orientation at the time the captured image data was generated. Other alternative embodiments incorporating the automatic RLOS 324 and UDOS 326 sensors could provide for an override function that instructs the processing and storage subsystem 208 to ignore the orientation signals generated by the RLOS 324 and UDOS 326 sensors, enabling the user to retain full manual control over the final orientation of the captured image data on the image display 100. The I/O Interface 414 is coupled to the internal bus 402 and has an external port connector for coupling the processing and storage subsystem 208 with a host computer (not shown) for downloading image data stored in the volatile memory 410 and thus freeing up room in the volatile memory 410 for additional sets of processed image data. In the second and alternative embodiment discussed above where the processing and storage subsystem 208 is a desktop type computer, the input device 408 will also include a keyboard and mouse type controller.

Referring now to FIG. 4B, a block diagram is shown illustrating a volatile memory 410 within the processing and storage subsystem 208. The volatile memory 410 contains a frame buffer 416, working memory 418 and storage memory 420 coupled to the internal bus 402. The volatile memory 410 is preferably a Random Access Memory (RAM).

The frame buffer 416 is preferably comprised of a dedicated space of contiguous memory comprising an i-row by j-column area for storing image data. There is preferably a constant one-to-one correspondence between the pixels comprising the image sensor 304 array and the storage locations within the frame buffer 416 area. Alternatively, the pixel signals from the image sensor 304 array could be stored within the frame buffer 416 in a non-contiguous (i.e. sectorized) memory format, as is commonly known in the art. In the preferred embodiment, i and j are set equivalent to the size of the image sensor 304. Since the preferred image sensor 304 is a 481 by 641 array, i is set to 481 and j is set to 641. In alternative embodiments where the image sensor 304 is only a 480 by 640 array, the frame buffer 416 will still

preferably be a 481 by 641 array since, as is discussed below, an extra row and column is generated by the processing and storage subsystem 208.

The working memory 418 preferably provides a temporary space for storing data received from the input device 408 and for data generated by the processing unit 404. The working memory 418 also contains additional memory for storing the RLOS 324 and UDOS 326 signals at the time the image data was captured by the image sensor 304; and additional information conventionally associated with the capture process, such as exposure and focus settings, time and date, statistical data, and the presence of any defective pixels, rows or columns within the image sensor 304.

The storage memory 420 preferably provides space for storing multiple sets of image data, until the images are off-loaded from the camera 200 via the I/O interface 414. The storage memory 420 sets a maximum image data holding capacity of the camera 200. Alternatively, additional memory cards could also be coupled to the internal bus 402, providing even more image data storage capability. Such an additional memory card could be a non-volatile flash memory card.

Referring now to FIG. 4C, a block diagram is shown illustrating a memory map of a volatile memory data structure 417 within the volatile memory 410. The volatile memory data structure 417 comprises an image data field 419 for storing the captured image data, an RLOS signal data field 421 for storing the RLOS 324 signal, an UDOS signal data field 423 for storing the UDOS 326 signal and a miscellaneous data field 425 for storing the exposure and focus settings, time and date, statistical data, and the presence of any defective image sensor 304 pixels, rows or columns. The interactions of each of all these data fields 419, 421, 423, 425 with the camera 200 is described in detail below.

Referring now to FIG. 4D, a block diagram is shown illustrating the non-volatile memory 406 within the processing and storage subsystem 208. The non-volatile memory 406 comprises an auto-rotate unit 422, an image processing unit 424, an image capture unit 428 and an operating system unit 426.

The image capture unit 428 controls the imaging subsystem's 204 focus and aperture settings; captures the image data; routes the image data into the frame buffer 416; routes the exposure and focus settings, time and date, statistical data, and the presence of any defective image sensor 304 pixels, rows or columns into the miscellaneous data field 425; generates additional rows and columns of image data within the frame buffer 416 if required; monitors the RLOS 324 and UDOS 326; and sets the RLOS signal 421 data field and the UDOS signal 423 data field based on the RLOS 324 and UDOS 326 outputs. In the preferred embodiment the image capture unit 428 corrects any pixel defects within the image sensor 304 using the information stored in the miscellaneous data field 425 before passing the image data to the auto-rotate unit 422. In an alternative embodiment, image processing unit 424 corrects any pixel defects within the image sensor 304 using the information stored in the miscellaneous data field 425 after receiving the image data from the auto-rotate unit 422. In this alternative embodiment, the defective image sensor 304 pixel information must also be rotated by the auto-rotate unit 422 in the same manner as for the image data, described below.

The image capture unit 428 preferably is designed in two embodiments, a hardware embodiment and a software embodiment; however, the hardware embodiment is preferred.

#### Hardware Embodiment

In the hardware embodiment, the image sensor 304 is comprised of at least one more extra row and column than the image processing unit 424 is designed to process. Thus, if the image processing unit 424 is designed to process a 480 by 640 pixel signal array, then the image sensor 304 must be at least a 481 by 641 pixel array (i.e. "i" is 481 and "j" is 641 in FIG. 3C). The discussion that follows on the auto-rotate unit 422 makes clear when and why the additional row and column is required.

#### Software Embodiment

The software embodiment is required when the image sensor 304 lacks any additional rows and columns beyond those that the image processing unit 424 is designed to process. For Bayer pattern image processing, the image capture unit 428 must generate an additional row and column of image data. (For non-Bayer pattern image data, a straightforward rotation is performed as is described below and an additional row and column is not required.) Thus, for example, if the image sensor 304 is comprised of a 480 by 640 pixel array and the image processing unit 424 is designed to process a 480 by 640 array, then the image capture unit 428 must generate an additional row and column of pixels. In the preferred software embodiment, the additional row generated corresponds to row  $r_i$  (i.e. GRGRGR) in FIG. 3C and the additional column generated corresponds to column  $c_j$  (i.e. GBGBGB) in FIG. 3C. The additional row and column may be generated in any number of ways, including: setting the additional pixels to black; creating a duplicate of a nearby line of pixels with the same pixel pattern (i.e. two pixel lines over); generating a duplicate of the nearest color (i.e. G's would be copied from one pixel line over while R's or B's would be copied from two pixel lines over); setting the pixel values based on a filtering algorithm which looks at a number of nearby pixels; or setting the additional row and column of pixels randomly.

The auto-rotate unit 422 transforms the captured image data into the rotated image data for further processing by the image processing unit 424. The image processing unit 424 receives the rotated image data from the auto-rotate unit 422 and transforms it into processed image data, ready for saving in the storage memory 420. The operating system unit 426 is coupled to the internal bus 402 and preferably comprises a conventional set of program instructions for controlling the configuration and usage of the computer's 208 hardware resources. The operations performed by the auto-rotate unit 422 and the image processing unit 424 are described in more detail below.

Referring now to FIGS. 5A, 5B and 5C, a graphical representation is shown in FIG. 5A illustrating portrait\_left image data within the frame buffer 416; a graphical representation is shown in FIG. 5B illustrating portrait\_right image data within the frame buffer 416; and a graphical representation is shown in FIG. 5C illustrating landscape image data within the frame buffer 416. FIGS. 5A, 5B and 5C all show the same image data 419 within the frame buffer data structure 417 filled with different sets of captured image data and graphically positioned in the orientation in which the camera 200 was held at the time the captured image data was generated. As will be discussed in detail below, the shaded areas represent a subset of pixel signals within the image data field 419 that the auto-rotate unit 422 selects to be sent to the image processing unit 424 as the rotated image data.

The auto-rotate unit 422 preferably comprises program instructions stored in the non-volatile memory 406 that are executed by the processing unit 404. The auto-rotate unit

422 controls the flow of data between the frame buffer 416 and the image processing unit 424. First, the auto-rotation unit 422 accesses the RLOS signal 421 data field and UDOS signal 423 data field from the frame buffer data structure 417; and, based on this orientation data, selects either a portrait\_left spooling routine, a portrait\_right spooling routine or a landscape spooling routine. The spooling routines select-out and feed the captured image data stored in the image data field 419 to the image processing unit 424. "Spooling" is here defined as a routine for transferring data from one unit or device to a second unit or device. It is through these spooling routines that the auto-rotate unit 422 transforms the captured image data into the rotated image data. While the effect of the auto-rotate unit 422 is only described below with reference to the captured image data, some of the additional information stored in the working memory 418 (such as the location of any defective pixels, rows or columns within the image sensor 304) will also be rotated, as described above. This additional information is then used by the image processing unit 424. Alternatively, a defective pixel correction algorithm can be applied to the image data prior to rotation of the image data. Each of the different spooling routines are described in detail below.

First, the auto-rotate unit 422 determines the image sensor's 304 orientation at the time the image was captured, by accessing the RLOS signal 421 and UDOS signal 423 data fields. Next, if the RLOS signal 421 data field contains a portrait\_left signal and the UDOS signal 423 data field contains a level signal, the auto-rotate unit 422 selects the portrait\_left spooling routine. However, if the RLOS signal 421 data field contains a portrait\_right signal and the UDOS signal 423 data field contains a level signal, the auto-rotate unit 422 selects the portrait\_right spooling routine. Lastly, if the RLOS signal 421 data field contains a landscape signal and the UDOS signal 423 data field contains a level signal, or whenever the UDOS signal 423 data field contains an off-level signal, regardless of what the RLOS signal 421 data field contains, the auto-rotate unit 422 selects the landscape spooling routine. Each of the three spooling routines within the auto-rotate unit 422 are now discussed below.

If the portrait\_left spooling routine is selected, the auto-rotate unit 422 interprets the captured image data within the image data field 419 as shown in FIG. 5A. FIG. 5A shows an i-row by j-column set of captured image data in a portrait\_left orientation. As shown, the "TOP" of the portrait\_left orientation corresponds to column  $c_2$ . Note that the "row" and "column" designations defined for the image sensor 304 in FIG. 3C are retained for clarity in FIGS. 5A, 5B and 5C even though the camera has been rotated into the portrait\_left orientation. Conventional image processing units are designed to receive image data in a constant pixel pattern format. Using the Bayer pattern format (assumed for the purposes of this discussion) the image processing unit 424 must receive the image data from the image data field 419 starting with a "GRGRGR" line and followed by a "BGBGBG" line, in an alternating line-by-line pattern. Therefore, a subset of the image data field 419 is selected by the portrait\_left spooling routine, as shown by the shaded gray area in FIG. 5A, to be sent to the image processing unit 424. The shaded area of FIG. 5A is defined from rows  $r_1$  to  $r_{i-1}$ , and from columns  $c_2$  to  $c_j$ . The total array size of the shaded area is therefore comprised of  $i-1$  number of rows and  $j-1$  number of columns. Next, the portrait\_left spooling routine defines the shaded area of  $c_2$  as the top line of the rotated image data and configures the image processing unit 424 to accept a line length of  $i-1$  pixels. The portrait\_left spooling routine first transfers the pixel signal in the image

data field 419 location  $(r_{i-1}, c_2)$  to the image processing unit 424. Decrementing the row number by one, the portrait\_left spooling routine next transfers the pixel signal at location  $(r_{i-2}, c_2)$  to the image processing unit 424, and so on until pixel  $(r_1, c_2)$  has been transferred. The portrait\_left spooling routine then increments the column by one to  $c_3$  and resets the row to  $r_{i-1}$  in preparation for spooling the next line of pixel signals (having a length of  $i-1$ ) to the image processing unit 424, in the same manner as the first line (having a length of  $i-1$ ) was spooled. The portrait\_left spooling routine continues to increment the column number and spool the next line of pixel signals (having a length of  $i-1$ ) to the image processing unit 424 until column  $c_j$  has been spooled. The pixel signals within either row  $r_i$  or column  $c_1$  are not sent to the image processing unit 424 since the image processing unit 424 is preferably designed to process only an  $i-1$  by  $j-1$  array of pixel signals. As a result of this spooling sequence, the entire set of pixel signals representing a portrait\_left image has been transferred to the image processing unit 424. Furthermore, due to this specific spooling sequence, the portrait left image will be displayed on the image display 100 so that the "TOP" of the portrait\_left image corresponds to the top 102 of the image display 100.

If the portrait\_right spooling routine is selected, the auto-rotate unit 422 interprets the captured image data within the image data field 419 as shown in FIG. 5B. FIG. 5B shows an i-row by j-column set of captured image data in a portrait\_right orientation. As shown, the "TOP" of the portrait\_right orientation corresponds to column  $c_{j-1}$ . A subset of the image data field 419 is selected by the portrait\_right spooling routine, as shown by the shaded gray area in FIG. 5B, to be sent to the image processing unit 424. The shaded area of FIG. 5B is defined from rows  $r_2$  to  $r_i$ , and from columns  $c_1$  to  $c_{j-1}$ . The total array size of the shaded area is therefore comprised of  $i-1$  number of rows and  $j-1$  number of columns. Next, the portrait\_right spooling routine defines the shaded area of  $c_{j-1}$  as the top line of the rotated image data and configures the image processing unit 424 for a line length of  $i-1$  pixels. The portrait\_right spooling routine first transfers the pixel signal in the image data field 419 location  $(r_2, c_{j-1})$  to the image processing unit 424. Incrementing the row number by one, the portrait\_right spooling routine next transfers the pixel signal at location  $(r_3, c_{j-1})$  to the image processing unit 424, and so on until pixel  $(r_i, c_{j-1})$  has been transferred. The portrait\_right spooling routine then decrements the column by one to  $c_{j-2}$  and resets the row to  $r_2$  in preparation for spooling the next line of pixel signals (having a length of  $i-1$ ) to the image processing unit 424, in the same manner as the first line (having a length of  $i-1$ ) was spooled. The portrait\_right spooling routine continues to decrement the column number and spool the next line of pixel signals (having a length of  $i-1$ ) to the image processing unit 424 until column  $c_1$  has been spooled. Thus, the entire set of pixel signals representing a portrait\_right image has been transferred to the image processing unit 424. As a result of this specific spooling sequence, the portrait\_right image will be displayed on the image display 100 so that the "TOP" of the portrait\_right image corresponds to the top 102 of the image display 100.

If the landscape spooling routine is selected, the auto-rotate unit 422 interprets the captured image data within the image data field 419 as shown in FIG. 5C. FIG. 5C shows an i-row by j-column set of captured image data in a landscape orientation. As shown, the "TOP" of the landscape orientation corresponds to  $r_1$ . A subset of the image data field 419 is selected by the landscape spooling routine, as shown by the shaded gray area in FIG. 5C, to be sent to

the image processing unit 424. The shaded area of FIG. 5C is defined from rows  $r_1$  to  $r_{i-1}$ , and from columns  $c_1$  to  $c_{j-1}$ . The total array size of the shaded area is therefore comprised of  $i-1$  number of rows and  $j-1$  number of columns. Next, the landscape spooling routine defines the shaded area of  $r_1$  as the top line of the rotated image data and configures the image processing unit 424 for a line length of  $j-1$  pixels. Alternatively, the shaded gray area representing the rotated image data could be positioned over different sets of pixel signals within the image data field 419, again subject to the constraint that the top line begin with the "GRGRGR" pattern. The landscape spooling routine first transfers the pixel signal in the image data field 419 location  $(r_1, c_1)$  to the image processing unit 424. Incrementing the column number by one, the landscape spooling routine next transfers the pixel signal at location  $(r_1, c_2)$  to the image processing unit 424, and so on until pixel  $(r_1, c_{j-1})$  has been transferred. The landscape spooling routine then increments the row by one to  $r_2$  and resets the column to  $c_1$  in preparation for spooling the next line of pixel signals (having a length of  $j-1$ ) to the image processing unit 424, in the same manner as the first line (having a length of  $j-1$ ) was spooled. The landscape spooling routine continues to increment the row number and spool the next line of pixel signals (having a length of  $j-1$ ) to the image processing unit 424 until row  $r_{i-1}$  has been spooled. Thus, the entire set of pixel signals representing a landscape image has been transferred to the image processing unit 424. As a result of this specific spooling sequence, the landscape image will be displayed on the image display 100 so that the "TOP" of the landscape image corresponds to the top 102 of the image display 100.

Also as introduced above, the image processing unit 424 preferably comprises program instructions stored in the non-volatile memory 406 that are executed using the processing unit 404. The image processing unit 424 receives the rotated image data from the auto-rotate unit 422, performs conventional image processing operations (such as white balancing, reconstruction, color correction, gamma correction, sharpening and compression) on the rotated image data; generates processed image data; and either saves the processed image data to the storage memory 420 or outputs it to a host computer (not shown) via the I/O interface 414. As was discussed above, the image processing unit 424 is preferably implemented such that it must receive all the image data spooled from the frame buffer 416 starting with a "GRGRGR" line followed by a "BGBGBG" line in an alternating line-by-line pattern. This is the image processing unit's 424 design limitation which drives the auto-rotate unit's 422 particular pixel selection routines described above. Alternatively, a different image processing unit 424 could be implemented which requires that the image data be spooled from the frame buffer 416 starting with a "GBG-BGB" line followed by a "RGRGRG" line or any combination of the Bayer pattern.

Those skilled in the art will also recognize that alternate embodiments of the present invention that do not use the Bayer pattern may still use the teachings of present invention to rotate their image data. In such alternative embodiments the auto-rotate unit 422 performs a straightforward rotation of the image data since such alternative image processing units 424 may accept pixel signals in any orientation. Thus for the straightforward rotation where the shaded gray area of FIG. 5C represents the image data, the portrait\_left spooling routine would start with pixel signal  $(r_{i-1}, c_1)$ , spool column  $c_1$ , increment the column to  $c_2$ , spool column  $c_2$  and so on; the portrait\_right spooling routine would start with pixel signal  $(r_1, c_{j-1})$ , spool column  $c_{j-1}$ ,

decrement the column to  $c_{j-2}$ , spool column  $c_{j-2}$  and so on; and the landscape spooling routine would start with pixel signal  $(r_1, c_1)$ , spool row  $r_1$ , increment the row to  $r_2$ , spool row  $r_2$  and so on. In all three cases above, the extra or provided row  $r_i$  and extra or provided column  $c_j$  would not be transferred.

Referring now to FIGS. 6A, 6B, 6C and 6D, a flowchart of a preferred method for rotating the display orientation of a captured image is shown. The method begins in FIG. 6A with step 600 where the image capture unit 428 captures a set of image data and a set of image sensor 304 orientation data approximately simultaneously. The RLOS 421 and UDOS 423 orientation signals are recorded when the image data capture occurs in order to insure that the orientation sensor information accurately reflects the actual position of the image sensor 304. In step 602, the image capture unit 428 transfers the captured image data and the image sensor 304 orientation data into the volatile memory 410. In Step 603, the image capture unit 428 generates an additional row and column of image data if the captured image data does not already include an extra row and column of image data. In Step 604, the auto-rotate unit 422 determines the orientation of the captured image data. If in step 606 the captured image data is in a portrait\_left orientation, the method proceeds to step 612, otherwise the method continues to step 608. If in step 608 the captured image data is in a portrait\_right orientation, the method proceeds to step 628, otherwise the method proceeds to step 644.

In step 612 of FIG. 6B, the auto-rotate unit 422 configures the image processing unit 424 to accept an image data line length corresponding to a portrait\_left image. In step 614, the auto-rotation unit 422 initializes a variable named "column" stored in the working memory 418 to a first pixel column (i.e. to column  $c_2$ ), within the image data field 419, required by the image processing unit 424. In step 616, the auto-rotation unit 422 initializes a variable named "row" stored in the working memory 418 to a row (i.e. to row  $r_{i-1}$ ) within the image data field 419 containing a first pixel color required by the image processing unit 424. Next, in step 618, the auto-rotate unit 422 transfers the captured image data in the image data field 419 location  $(r_{row}, c_{column})$  to the image processing unit 424. In step 620, the auto-rotate unit 422 decrements "row" to a row containing a next pixel color required by the image processing unit 424. In step 622, if "last row" has been transferred, the method proceeds to step 623, otherwise the method returns to step 618. In the preferred embodiment "last row" is " $r_1$ " as shown in FIG. 5A. When "last row" has been transferred in step 622, an entire line of portrait\_left image data has been transferred to the image processing unit 424. In step 623 the image processing unit 424 performs any required image processing on the transferred image data. Step 624 then increments "column" to a next pixel column required by the image processing unit 424. Finally, if in step 626 "last column" has not yet been transferred the method returns to step 616, otherwise the method ends. In the preferred embodiment "last column" is " $c_j$ " as shown in FIG. 5A.

In step 628 of FIG. 6C, the auto-rotate unit 422 configures the image processing unit 424 to accept an image data line length corresponding to a portrait\_right image. In step 630, the auto-rotation unit 422 initializes a variable named "column" stored in the working memory 418 to a first pixel column (i.e. to column  $c_{j-1}$ ), within the image data field 419, required by the image processing unit 424. In step 632, the auto-rotation unit 422 initializes a variable named "row" stored in the working memory 418 to a row (i.e. to row  $r_2$ ) within the image data field 419 containing a first pixel color